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FIELD EVALUATION OF GRAVITY-FED SURFACE DRIP IRRIGATION SYSTEMS IN A SLOPED GREENHOUSE

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ABSTRACT

This study was conducted to evaluate the water application uniformity for a surface drip irrigation system, considering water quality and field slope. The uniformity parameters like average emitter discharge q_a , relative emitter discharge R, standard deviation of emitter flowrate S_q coefficient of variation of emitter flow Cv, statistical uniformity Us, emission uniformity EU and Uniformity coefficient Uc were determined for a gravity-fed surface drip irrigation system installed on a slanted land (5.34 % slope). The discharge recorded along the lateral length was 0.74 l/h and 0.69 l/h for section 1 and 2 respectively. These were higher than the manufacturers specification of 0.5 to 0.6 l/h. The values of Us, EU and Uc were quite high for the two sections. The Cv, Us, EU and Uc obtained were 0.14, 86 ± 3%, 90% and 93% respectively in Section-1 and 0.15, 85 ± 3%, 83% and 87% respectively in Section-2. The overall performance description for Cv, Us, EU and Uc were very good, good, excellent and excellent respectively for Section-1 and very good, good, good and good respectively in Section-2. The study also revealed that the mean emitter discharge for section 1 and section 2 were not significantly different at confidence level of 95% (P < 0.05). What affected the emitter discharge was not the water quality at the study site *but lack of proper cleaning and flushing of the flowline after fertigation activity. Periodic acidic injection and flushing was suggested to prevent clogging in the system.*

Key words: emitter uniformity, field slope, water quality, clogging, drip.

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1. INTRODUCTION

Drip or Trickle irrigation systems are specifically designed to apply known amount of water frequently, steadily, slowly and directly to the rootzone of plants on the field. It is an efficient form of irrigation that can have water application and crop water use efficiency as high as 90-95% [1] when properly designed, installed and managed. Drip irrigation system is becoming popular in Nigeria due to its ease of adoption and construction from local materials. There is an urgent need to increase water productivity and water application efficiency due to the continuos increase in population, increase in demand for vegetables and increased pressure on land available for agriculture copled with the overwelming effect of climate change [2]. There is the need to appropriately dispense and manage water as a scarce resource through the use of well managed water saving irrigation system.

Gravity-fed systems supply the entire drip irrigation system from an overhead tank. The water is made to flow under the influence of gravity and the pressure of water in the system is related to the ground level. This system targets individual plants and apply water only to the root zone, properly operating micro-systems save significant water and energy bills. Greenhouses in tropical regions protect crops from heavy rainfall, insect infestation and damages, high solar radiation, hail, and strong winds that can impact open field production. In hot regions, they reduce water stress through shading. The regional climate is therefore very important and will determine the type of construction and their functions.

Most of the systems have the water sources or overhead tanks located 1.5 – 2m above the ground level outside the green houses while questions are being asked on what will the effect of head on the mainline pressure and emitter dischages down the lateral line. Irrigation uniformity is the most important reason for evaluation of the irrigation system performance and is affected by the field topography, hydraulic design of drip system as well as level of partial or complete clogging [3-5]. Irrigation scheduling must be adjusted to meet the evapotranspirtion losses hence the need to verify the emitter discharge from time to time. Manufacturers of drip irrigation systems often provide scanty information and data for systems operating under low pressure [6] . Poor unformity of water application results in portions of drip irrigation systems receiving little or no water discharges leading to poor crop yields as seen by [7]. Experience has shown that emmiter discharge decline after some months of system installation expecially when the applied water has high amount of suspended solids which the installed filter is incapable of handling, presence of nutrients and chemicals in the water which results in algea build up.

[5] suggested that evaluation is necessary annually to determine the effects of emitter plugging or changes in other components of system performance to diagnose and treat emitter plugging problems. Mainline flowrate and presure monitoring is to acertain when it is time to clean or replace the in-line filter, the effects of pressure variations in the pipe network

(hydraulic uniformity) due to site slope and variations due to the emitter characteristics (emitter performance variation) on uniformity of water application.

The uniformity in water distribution and performance of an irrigation system is shown by values of performance indicators of uniformity coefficient CU, distribution uniformity DU, Water application efficiency Ea, Relative emitter discharge R, Percentage of completely clogged emitters P_{clog} , Emission uniformity EU, Absolute uniformity emission EUa, Statistical uniformity Us, Coefficient of variation due to emiter performance on the field Vpf, [8-11].

[12] outlined the uncertainties in drip irrigation lateral parameters and showed that the supplied manufacturing values may be different than the effective field values due to manufacturing variations and other factors. [13] measured the uniformity of IDE low-cost drip systems at different heads of one to three meters. They showed that the emitter discharge uniformity increased with increase in head. [11] identified inadequate working pressure and high pressure differences in subunits caused by installation and design problems, lack of knowledge of irrigation scheduling, ability to know how to measure emitter discharges as the major causes of performance reduction in Iranian trickle irrigation systems. The objective of this study was to evaluate the performance of a gravity-fed surface drip system installed inside a sloped screenhouse and to determine the effect of water quality, land slope on emitter discharge along the dripline with an uphill and downhill flow.

2. MATERIALS AND METHODS

This study was carried out at the Teaching and Research Farm of Landmark University, Omu-Aran. The location is on latitude 8° 8′00″ N, longitude 5°6′00″ E and altitude 564 m above mean sea level. The site is located in the derived savanna ecological zone of Nigeria. The rainfall pattern is bimodal with peaks in June and October. The average total annual rainfall in the area was about 1227 mm with mean air temperature of 26.2°C and mean relative humidity of 75.9%. The soil in the site of the experiment is an Alfisol classified as Oxic Hap-lustalf or Luvisol [14].

2.1. Water Quality Determination

Samples of water applied through the drip irrigation systems were taken during the field test to determine those important parameters that affect emitter clogging as in [11]. Parameters tested for were electrical conductivity (EC), pH, total suspended solids (TSS), total dissolved solids (TDS), total iron (Fe), calcium (Ca), magnesium (Mg), manganese (Mn), bicarbonates (Bc), and bacterial count (BC). Water analyses were carried out in the laboratory using standard procedures [15]. The soil physicochemical properties in the study area was also determined using standard laboratory methods.

2.2. Evaluation Procedure

The evaluation was carried out according to [9; 4; 10; 1; 16]. These procedures are based on taking measurements of emitter discharge along selected driplines on a sub-main. Four positions were tested on each driplines which is 11.5 m long each: one located on the first emitter point close to the inlet, one at the far end, and two in the middle at the one-third and two-thirds positions. Each driplines are identified as L1, L2, L3……L12, emitter position on each driplines are identified as A, B, C, and D starting from the emitter point near the submain line to the 4^{th} point on the dripline which is D. Thus, the catch can was identified as L1A, L1B…L1D, same for L2A to L2D and up to L12A to L12D. This gives a total of 48 measurement positions as there were 12 driplines in each screenhouse evaluated. The screenhouse under study was divided into two sections and were identified simply as SEC1 and SEC2. SEC1 has its flow downhill while SEC2 flow uphill. Leakages on the mainline, submain line and all driplines were checked and fixed. The layout plan for the tested drip systems, showing the position of the selected discharge points are shown as Figure1.0 .

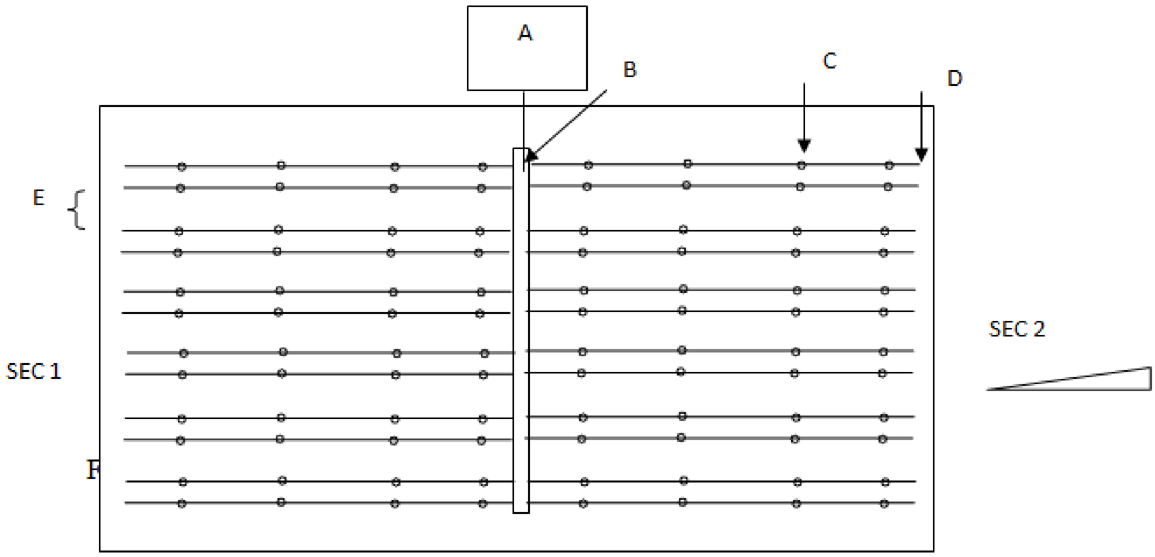

Figure 1.0 The drip system layout in the screenhouse.

A- overhead water tank, **B-** submain line, **C-** emitter point, **D-** dripline (L1), **E-** alley.

The slope of the elevation of the highest point in section 2 and that of the lowest point in section 1 was measured using a dumpy level to be 5.34 %

2.3. Data Collection Method

The drip system was operated at operational pressure for enough time to remove all the air bubbles from the lines before water was collected in the sampling containers. A known size container (100 ml) was used to collect water flow from each dripper, the time required to fill the container was recorded using a stopwatch and used in calculating the flowrate of each of the selected drippers. The flowrate was calculated and recorded along selected points on each line for analysis. An acceptable confidence interval to prove that readings were precise as the ones obtained from [1] was determined.

To avoid over irrigation, since the number of data points were many, four assistants were trained and assisted in sample collection one for each points and data were recorded in the data sheet. Three replicates of each data points were taken and the average value was recorded as the point data. The data obtained was processed and analyzed to assess the overall water application uniformity of the gravity fed drip irrigation systems on the field.

2.4. Parameters Used to Evaluate Drip Emitters

The following parameters were used to evaluate the gravity fed drip system based on the measured data in the study area and were as follows:

Average Emitter Discharge Rate (q_a). The mean amount of water released by each dripper per unit time is the Average emitter discharge rate (q_a). It is obtained by Eq1

$$q_a = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad (1)$$

where: qi = flow rate of the emitter i (m^3/s) or (l/h)

n = Total number of emitters.

Relative Emitter Discharge R, was Calculated as:

$$R = q_a \,/\, q_n \tag{2}$$

where: q_a = mean emitters discharge for each measurement (l/h)

q_n = emitters nominal discharge (l/h)

Standard deviation of emitter flow rate (Sq): can be written as:

$$Sq = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(q_i - q_a\right)^2} \tag{3}$$

Where all terms are as described Eq 1- 3 above

The Coefficient of Variation of Emitter Flow, Cv, [17] evaluates the variability of flow and is computed by dividing the standard deviation by mean. Manufacturers usually publish the coefficient of variation for each of their products. Cv can be expressed as:

$$Cv = \frac{S_q}{q_a} \tag{4}$$

where:

S_q = Standard deviation of emitter flow rate

q_a = average emitter discharge rate, l/h

The classification of coefficient of variation is as shown in Table 2.1.

Table 2.1 Classification of coefficient of variation

Coefficient of variation, Cv	Classification
> 0.4	Unacceptable
0.4- 0.3	Low
0.3- 0.2	Acceptable
0.2- 0.1	Very good
<0.1	Excellent

Statistical Uniformity (Us) used to evaluate water application uniformity within a submain unit throughout a micro irrigation system. It is determined by Eq (5) [18]

$$Us = 100\,(1 - Cv) \tag{5}$$

where:

Cv = coefficient of variation.

A micro-irrigation system uniformity classification has been developed to characterize the emitters based on Us and EU [9] and presented in Table 2.2

Table 2.2 Comparison between Us and EU as suggested for design purpose

Classification	Us (%)	EU (%)
Excellent	≥ 90	94 – 100
Good	80 - 90	81 - 87
Fair	70 - 80	68 - 75
Poor	60 - 70	56 - 62
Unacceptable	<60	<50

Source: [9].

Emission Uniformity (EU) Emission uniformity (*EU*) is determined as a function of the relation between the average flow emitted by 25% of the emitters with the lowest flow and the mean flow emitted by all emitters, as shown in Eq. (6). [19;16]

$$Eu = 100\ \frac{\bar{q}_{25\%\,min}}{\bar{q}} \qquad (6)$$

where:

EU = emission uniformity (%)

$\bar{q}_{25\%\,min}$ = average of 25% of the lowest values of flow rate (l/h)

$\bar{q}$ = average flow rate (l/h)

The evaluated system is classified according to the EU values, following [8] and [20] (Table 2.3).

Table 2.3 System classification according to emission Uniformity (EU) values

	Classification	
EU (%)	**MERRIAM and KELLER (1978)**	**CAPRA and SCICOLONE (1998)**
<66	poor	low
66 – 70	poor	mean
80 - 84	acceptable	
80 - 84	good	
84 - 90	good	high
> 90	excellent	

Uniformity Coefficient (UC). The water application uniformity of drip irrigation system was evaluated using the uniformity coefficient formula developed by [21; 22], which is represented in ASABE standards as:

$$UC = 100\left[1 - \frac{1}{n\,q_a}\sum_{i=1}^{n}|q_i - q_a|\right] \qquad (7)$$

where: n = number of emitters under consideration

q_a = mean flowrate of the emitter (l/h)

qi = flowrate of the emitter *i* (l/h)

The Uniformity coefficient is as classified in Table 2.4

Table 2.4 Classification of Uniformity coefficient

Uniformity coefficient, UC (%)	Classification
Above 90	Excellent
80 - 90	Good
70 - 80	Fair
60 - 70	Poor
< 60	Unacceptable

Source: [17]

2.5. Data Analysis

The recorded flowrate of each sampled point in the system was arranged in ascending order (ranked) using an excel spreadsheet. From the result obtained, the outliers, the very smallest and highest flowrates not consistent with the rest of the recorded flowrates were left out.

The maximum flowrates Q_{max}, minimum flowrates Q_{min} and average flowrates Q_{avg} obtained from each sample in each section were used to calculate their Cv and EU. Analysis of variance (ANOVA) at 95% confidence interval were used to test a hypothesis that the mean discharge and EU for the two sections under study were statistically equal. The test uses the t - test in the hypothesis testing with two samples assuming unequal variances.

3. RESULTS AND DISCUSSIONS

3.1. Water Quality Evaluation

The physical, chemical and biological characteristics of the untreated borehole used for the drip irrigation in the study area are shown in Table 3.1. All parameter where found to be below the level of concern. Turbidity as an indicator of water clogging potential was also found to be very low, the same with the level of TSS. The fact that Fe, H_2S, Mn and Bacterial count were not detectable is an indication that bacterial slimming which causes precipitation, sedimentation and clogging is not likely to occur. These results also indicate that borehole water was clearer than and contained less dissolved substances value of which is very good [23]. The slightly acidic pH level of borehole water was not strong enough to prevent clogging especially after long accumulation of suspended solids and mineral precipitation even though it is suitable for agricultural uses.

Table 3.1 Clogging potential constituents of water samples in the study area

Parameters					*Level of concern		
	Max	Min	Avg	SD	Low	Moderate	High
Turbidity (NTU)	0.01	0.001	0.01	0.00	-	-	-
EC (ms/cm) x 10^2	3.4	2.75	3.00	0.23	-	-	-
pH	5.57	5.68	5.72	0.00	< 7.0	7.0-8.0	> 8.0
TSS (mg/l)	0.73	0.16	0.37	0.24	< 50	50-100	> 100
TDS (mg/l)	0.34	0.15	0.23	0.07	< 500	500-2000	> 2000
Fe (mg/l)	ND	ND	ND	ND	< 0.2	0.2-1.5	> 1.5
Ca (mg/l)	7.05	1.90	3.67	2.36	-	-	-
Mg (mg/l)	0.94	0.75	0.84	0.07	-	-	-
H_2S (mg/l)	ND	ND	ND	ND	< 0.2	0.2-2.0	> 2.0
BOD_5 (mg/l)	9.5	9.1	9.3	0.30	-	-	-
Mn (mg/l)	ND	ND	ND	ND	< 0.1	0.1-1.5	> 1.5
Bacterial count(#/ml)	ND	ND	ND	ND	< 10,000	10-50,000	> 50,000

source: [24] * sourced from smart-fertilizer.com , ND- Not Detected

The higher level of BOD_5 which was above Standard Organization of Nigeria (SON) permissible limit of 6 mg/l indicated high organic pollution. This could be linked to poor siting of the boreholes at a relatively low location which allow the accumulation of non-point contaminants.

The results of Physicochemical properties of the soil in the study area is presented in Table 3.2

Table 3.2 Mean (STD) of Soil Physical and Chemical Properties of the study site.

Parameters	Mean (STD)
Sand (%)	78.90 (±0.12)
Silt (%)	8.22 (±0.02)
Clay (%)	12.88 (±0.34)
Textural Class	Loamy sand
Bulk density (g/cm^3)	0.714 (±0.30)
Total porosity (%)	43.50 (±1.94)
pH (H_20)	5.80 (±1.06)
EC (dsm^{-1})	7.80 (±1.24)
N (%)	0.10 (±0.02)
K (Mol Kg^{-1})	0.88 (±0.21)
Ca (Mol Kg^{-1})	8.01 (±0.43)
P (%)	8.67 (±0.78)
Mg ($MolKg^{-1}$)	2.00 (±0.87)

3.2. Application Uniformity of the System

The performance indices of the surface drip irrigation system evaluated in the study are presented in Tables 3.3

Table 3.3 Results of performance indices of the studied irrigation system

S/N	Parameters	Unit	Section1	Section2
1	Average emitter discharge, Qa	(l/h)	0.74	0.69
2	Relative emitter discharge, R		1.2	1.2
3	Std. Dev of emitter discharge		0.1	0.1
4	Coefficient of variation, Cv		0.14	0.15
5	Statistical uniformity, Us	Us ± x*%	86± 3%	85± 3.2%
6	Emission uniformity, EU	%	90	83
7	Uniformity coefficient, UC	%	93	87
8	manufacturer discharge value	(l/h)	0.6	0.6

*Standard error

The flowrate along the lateral length ranged between 0.74 l/h and 0.69 l/h for section 1and 2 respectively. These were higher that the manufacturers specification of 0.5 to 0.6 l/h. Partial and total clogging of emitters which was noted in the unusual elevated value of mean emitter discharge is closely related to the quality of the irrigation water, and occurs as a result of multiple factors, including physical, biological and chemical agents [4;11]. Large formations of biological biofilm were observed on the surface of the pressure compensating emitters (PCE) which probably kept the flexible orifice open resulting in increase in emitter discharge. Otherwise, the variation is attributed to increase in operation head along the land slope and decrease in emission uphill since the submain line is located midway of the screen house and part of the water flow downhill (SEC1) and uphill (SEC2). The surface drip system cross section of the site is shown in Figure 3.1. Besides, the evaluation was done after a year of system utilization and fertigation without disinfection.

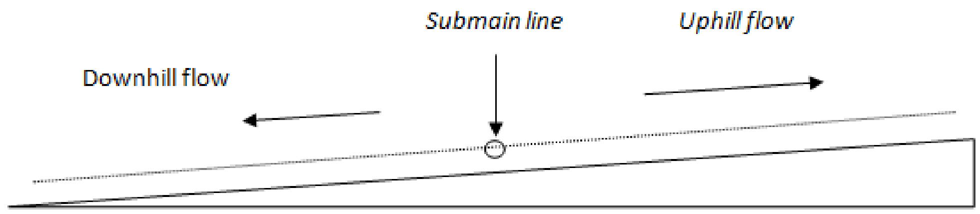

Figure 3.1 The cross section of the site with the location of submain and laterals

The findings of this study on the values of Us, EU and Uc were quite high for the two sections and higher than few reported studies [4; 16; 25]. The Cv, Us, EU and Uc were 0.14, 86± 3%, 90% and 93% respectively in Section-1 and 0.15, 85± 3.2%, 83% and 87% respectively in Section-2. The overall performance description for Cv, Us, EU and Uc were very good, good, excellent and excellent respectively for Section-1 and very good, good, good and good respectively in Section-2. It is desirable for Cv values to be as low, or as close to zero, as possible. When the coefficient of variation in emitter flowrates increases, the uniformity of water application decreases. The differences in the values of Cv, Us, EU and Uc can be attributed to the direction of flow which was downhill for section 1 and uphill for section 2. The application uniformity above 80% is an indicator of good performance of the system as recommended by [4].

3.3. Effect of Land Slope on Water Distribution

The variation in emitter discharge in relation to the flow direction and land elevation is shown in Table 3.4 and plotted in Figure 3.2. The discharge increases from the center line of the screen house which is at a distance of 11 m downhill and decreases uphill. This is purely a topographically induced occurrence and agrees with the findings of [26] and [27], in which Emission uniformity (EU) decreases drastically as the land slope increases from 0 to 4%. The decline is more pronounced when the slope increases in an upward direction where the bucket is placed on the lower side and the water flows up the slope.

Table 3.4: Screenhouse Field data in the study site

		downhill flow			**uphill flow**			
Distance (m)	1.0	4.0	7.0	10.0	*12.0*	*15.0*	*18.0*	*21.0*
Discharge(l/h)	0.73	0.72	0.72	0.78	*0.81*	*0.71*	*0.64*	*0.60*
Elevation (m)	1.720	1.595	1.465	1.270	*1.175*	*1.025*	*0.842*	*0.652*

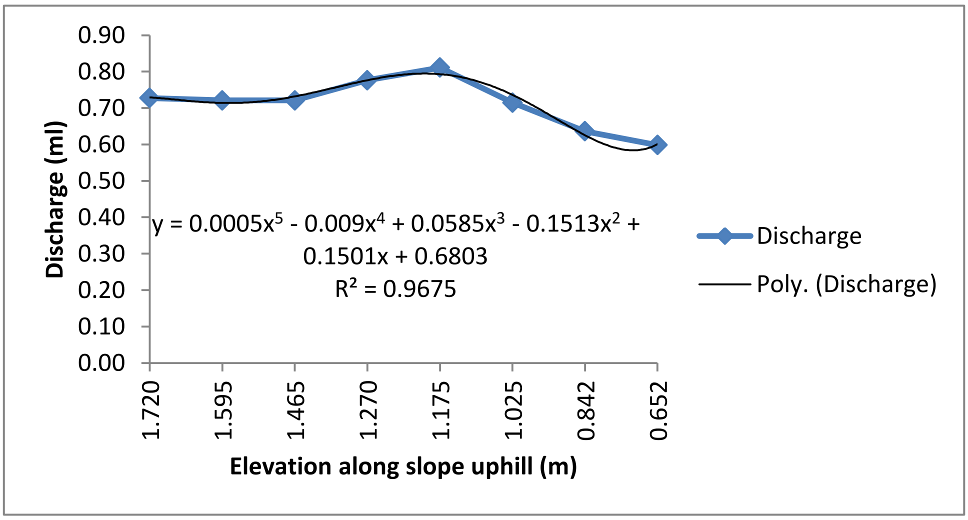

Figure 3.2 The plot of relationship between emitter discharge and site elevation

The emitter discharge variation mainly depends on pressure differences owing to difference in operation head. Other significant factors affecting emitter discharge include water temperature, quality with which the emitter is manufactured [28].

Emission uniformity (EU) decreases slightly up the slope this was with [13] who reported that the coefficient of uniformity (CU) and the distribution uniformity (EU) generally increase with increasing heads and decrease with increasing slope uphill.

4. STATISTICAL ANALYSIS RESULTS

The t-test used in the hypothesis testing reveals that the mean emitter discharge for section 1 and that of section 2 were not significantly different at confidence level of 95% ($P < 0.05$). The regression relationship between emitter discharge and elevation along the slope shows a linear relation as shown in equation (3) with R^2 value of 0.3477, an indication of a weak relationship.

$$\text{Elevation} = 3.180 * \text{discharge} - 1.050 \qquad (8)$$

$R^2 = 0.3477$ (weak relationship)

The discharge variation at various points on the laterals for section 1 and 2 are shown in Figure 3.3 and 3.4 respectively.

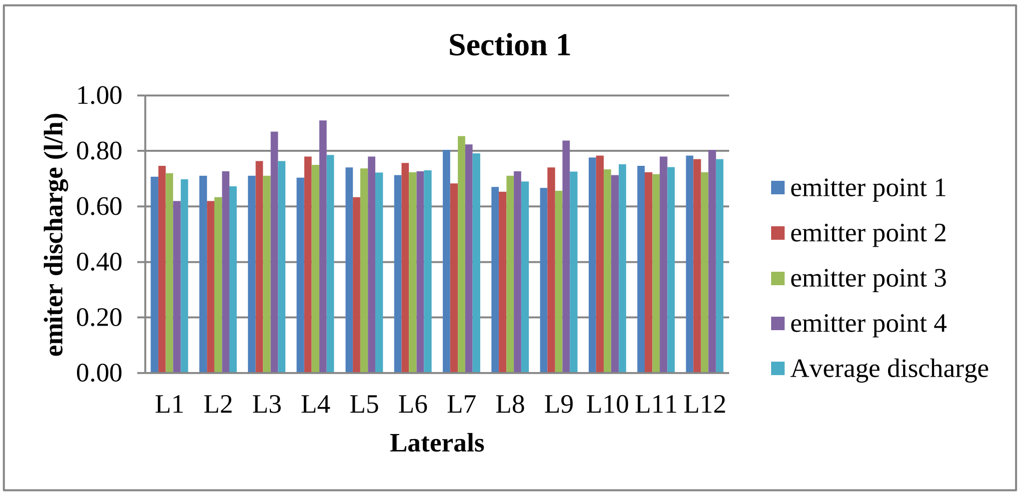

Figure 3.3 Discharge variation at various points on the laterals for section 1 (downhill flow)

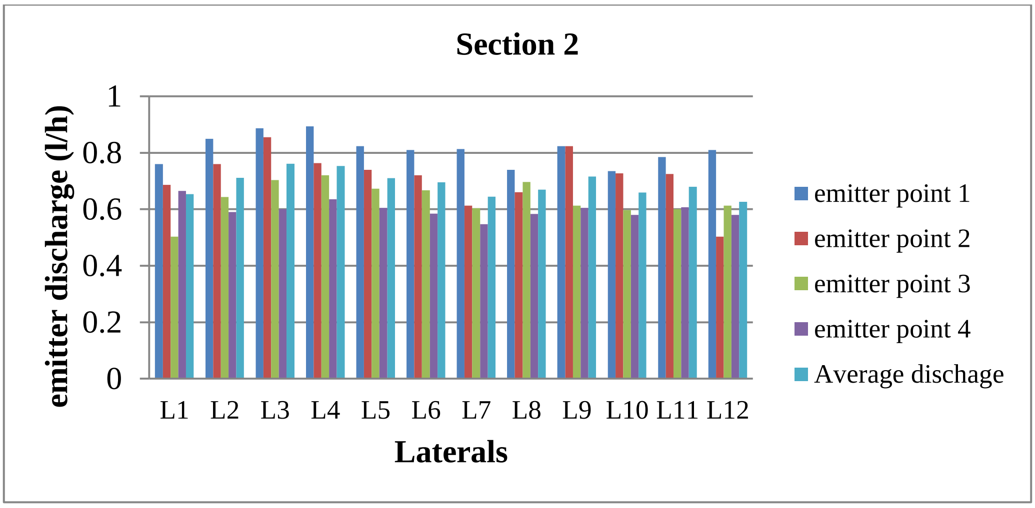

Figure 3.4 Discharge variation at various points on the laterals for section 2 (Uphill flow)

5. CONCLUSIONS

Evaluation of water application uniformity of gravity fed surface drip irrigation system is required periodically to ensure that the right emitter discharge is maintained. Results of the study revealed that the average discharge of surface drip emitter varied from 0.69 to 0.74 l/h under the pressure head of 2 m different from the manufacturer discharge value of 0.6 l/h.

The values of Cv, Us, EU and Uc were quite high for the two sections and found to be within the acceptable range even though clogging have occurred in the system due to inadequate maintenance of the system after two years of installation. The topography of the site of the drip system affected the average emitter discharge value uphill and downhill but not significantly at $P< 0.05$.

The water parameters that affect drip system clogging was found to be below clogging hazard potential limit. Hence the clogging was known to have been caused by non-flushing of the system after fertigation. The differences in the values of Cv, Us, EU and Uc can be attributed to the direction of flow which was downhill for section 1 and uphill for section 2.

What affected the emitter discharge was not the water quality at the study site but lack of proper cleaning and flushing of the flow line after fertigation activity which later led to continuous opening of the pressure compensating emitter orifice due to chemical precipitation and biomass accumulation. Periodic acidic injection and flushing is suggested especially after fertigation and long period of usage to prevent clogging in the system. The present study affirms the fact that proper flushing and site selection will affect the water application uniformity of gravity fed surface irrigation system.

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